Strategic Plan

for

International Collaborations

in

Fusion Science and Technology Research

February 1998

U.S. Department of Energy
Office of Energy Research
Office of Fusion Energy Sciences

Table of Contents

Introduction

The Office of Fusion Energy Sciences will pursue a strategy of enabling and participating in collaborative fusion research worldwide. The U.S. approach to international fusion collaborations is based on this "Strategic Plan for International Collaborations in Fusion Science and Technology Research". This strategy supports the overall United States fusion program strategy described in the "Strategic Plan for the Restructured Fusion Energy Sciences Program" (DOE/ER-0684, August 1996).

The approach to pursuing the International Thermonuclear Experimental Reactor (ITER) activities is contained in a letter from the Chair of the Fusion Energy Sciences Advisory Committee (FESAC), Dr. John Sheffield, to the Director of the Office of Energy Research in the Department of Energy, Dr. Martha Krebs, dated October 21, 1997; the FESAC advice was adopted in the letter from Martha Krebs to Dr. Sheffield dated November 20, 1997.

Technical options for collaborations other than ITER considered in developing the "Strategic Plan for International Collaborations in Fusion Science and Technology Research" were generated by the ad hoc Working Group on International Collaborations, chaired by Dr. N. Sauthoff of the Princeton Plasma Physics Laboratory. These technical options are presented in the working group's report, "Technical Opportunities for International Collaborations by the U.S. Fusion Program" (November 1997). The technical options were initially developed assuming that the U.S. will participate in a three year extension of the Engineering Design Activities. Once the key elements of the strategy were identified, the plan was examined to determine its sensitivity to that assumption. It has been determined that, while the overall U.S. fusion program would be severely affected, as might be the willingness of the international fusion community to attempt to establish new collaborative arrangements, the key technically-based strategic elements of international collaboration are to be insensitive to the assumption about our participation in ITER.

The “Strategic Plan for International Collaborations in Fusion Science and Technology Research”, the “Strategic Plan for the Restructured Fusion Energy Sciences Program”, and the “Technical Opportunities for International Collaborations by the U.S. Fusion Program” are available on the World Wide Web at the following address:

http://wwwofe.er.doe.gov/More_HTML/FusionDocs.html

A draft version of this document was reviewed by FESAC in January 1998 and the comments of the Committee have been incorporated into this document. The report of that FESAC review and the Sheffield to Krebs letter mentioned above are available on the World Wide Web at the following address:

http://wwwofe.er.doe.gov/More_HTML/FESAC_CHARGES_Reports

Executive Summary

The United States Government has employed international collaborations in magnetic fusion energy research since the program was declassified in 1958. These collaborations have been successful not only in producing high quality scientific results that have contributed to the advancement of fusion science and technology, they have also allowed us to highly leverage our funding. Thus, in the 1980s, when the funding situation made it necessary to reduce the technical breadth of the U.S. domestic program, these highly leveraged collaborations became key strategic elements of the U.S. program, allowing us to maintain some degree of technical breadth. With the recent, nearly complete declassification of inertial confinement fusion, the use of some international collaboration is expected to be introduced in the related inertial fusion energy research activities as well.

The United States has been a leader in establishing and fostering collaborations that have involved scientific and technological exchanges, joint planning, and joint work at fusion facilities in the U.S. and worldwide. These collaborative efforts have proven mutually beneficial to the United States and our partners.

International collaborations are a tool that allows us to meet fusion program goals in the most effective way possible. Working with highly qualified people from other countries and other cultures provides the collaborators with an opportunity to see problems from new and different perspectives, allows solutions to arise from the diversity of the participants, and promotes both collaboration and friendly competition. In short, it provides an exciting and stimulating environment resulting in a synergistic effect that is good for science and good for the people of the world.

The strategy for employing international collaborations is to:

> ***Identify and make use of opportunities to have U.S. scientists and engineers join with their counterparts in other countries to carry out research that uses the unique capabilities of fusion researchers and fusion facilities worldwide to achieve fusion program goals.***

This statement of our strategy is a revalidation and formalization of the strategy approach to international collaborations that has been used very successfully by the U.S. fusion program for the past twenty years. The Department will continue to support personnel exchanges and participation in joint experimental and theoretical research in a wide range of areas that have been the essential undergirding for large-scale collaborations. The Department will also seek to promote the use of expert groups on key scientific and technological issues facing fusion, building on the success of the International Thermonuclear Experimental Reactor (ITER) Physics Expert Groups and other less formal international groups.

The key elements supporting the strategy are shown below, grouped into three research areas.

(1) **Burning plasma physics and tokamak performance**

- participate in the three-year extension of the ITER Engineering Design Activities, restructuring that participation to emphasize development of lower cost design options to enhance the likelihood of constructing and operating a burning plasma physics facility, exploration of how these options may impact fusion development paths, and a refocusing of the U.S. Fusion technology program on meeting the needs of the restructured U.S. fusion energy sciences program.

- seek to discuss with the proper authorities on the European Union side the possibility that the U.S. could become a major collaborator on JET, the only existing fusion facility (currently authorized through 1999) with advanced performance capabilities that can operate with prototypic fusion powerplant fuels, Deuterium and Tritium.

- pursue development of an active collaboration on the physics of energy confinement and transport barrier formation on JT-60U, a flexible Japanese tokamak facility with equivalent break-even performance capability.

- promote international topical collaborations in the areas of size scaling, power and particle control and long pulse operation.

(2) **Innovative concept development**

- establish a program of international collaborations on spherical tori, including inviting international participation on the National Spherical Torus Experiment in the U.S.

- pursue opportunities for collaboration on stellarators through participation in the Large Helical Device program in Japan and the Wendelstein program in Germany.

- expand bilateral collaborations in Inertial Fusion Energy (IFE), and explore the incorporation of IFE issues into the fusion energy activities conducted under the auspices of the International Energy Agency.

(3) **Fusion technology and materials development**:

- begin discussions of future fusion development paths with our international colleagues.

- seek to deploy U.S. technologies on fusion experiments worldwide to access test conditions unavailable domestically, particularly on scientific issues related to long pulse/steady state operation, high power densities, and reliability.

- pursue the conduct of joint development work on the key feasibility issues for fusion technologies and materials, such as neutron irradiation effects, using unique fusion facilities worldwide.

Program Mission and Policy Goals

The international activities undertaken by the U.S. fusion energy sciences program support the overall program strategy as described in the "Strategic Plan for the Restructured U.S. Fusion Energy Sciences Program", (DOE/ER-0684, August 1996).

The **mission** of the fusion energy sciences program is to:

> ***Advance plasma science, fusion science, and fusion technology -- the knowledge base needed for an economically and environmentally attractive fusion energy source.***

The **policy goals** that support this mission are:

- ***understanding the physics of plasma, the fourth state of matter,***

- ***identifying and exploring innovative and cost-effective development paths to fusion energy, and***

- ***exploring the science and technology of energy producing plasmas, the next frontier in fusion research, as a partner in an international effort.***

Guiding Principles

The general principles that have guided the development of the international collaborations strategy are summarized below.

- While the perceived urgency of the energy goal differs among the countries funding fusion research, the common long-term goal of all of the fusion programs worldwide continues to be achieving practical fusion energy effectively.

- International collaboration brings together the best intellectual and facility capabilities worldwide.

- International collaborative efforts are a necessary, integral part of and contribute directly to the U.S. program.

- International collaboration, taken as a whole, should allow each participant to fulfill its own objectives.

- The most productive collaborations occur when all involved parties "bring something to the table".

- The greatest degree of success in international collaborations is attained when the work undertaken is given equal and high priority by the collaborating parties.

- The development of effective and productive international collaborations is based on mutual understanding and trust, and are facilitated by stable national commitments and funding.

- Technical breadth in collaborations is an advantage and should be maintained.

- Those areas where such collaborations are judged essential to meet U.S. program goals should be given priority.

- The application of state-of-the-art information technologies will greatly facilitate future international collaborations.

Situation Analysis

Most of the world's fusion research is funded by the European Union (EU), and the governments of Japan (JA), the Russian Federation (RF), and the United States. Smaller, but increasingly significant fusion programs are funded by Canada, China, India, and the Republic of Korea. Other countries are also funding fusion research activities, but at a level much lower than those mentioned above.

The yearly funding for the U.S. fusion program was reduced 40% between fiscal years 1995 and 1997. Between fiscal years 1977 and 1998, the U.S. fusion budget was reduced 70% in real terms. In contrast, funding for the European and the Japanese fusion programs has significantly increased during that same period. In fiscal year 1997, the EU spent nearly three times the amount spent by the United States for fusion research, while we estimate that the Japanese program spent about twice as much as the United States.

A consequence of the continuous reduction in the U.S. fusion budget has been the inability of the U.S. fusion program to make investments in major new experimental facilities. In contrast, the EU and Japan have continued to design and build such new fusion experiments.

In 1995, the Congress instructed the Department of Energy to restructure the U.S. fusion program to be consistent with the expectation that, with the reduced urgency for new energy sources in the U.S, budgets will remain flat for the foreseeable future. Thus, the U.S. is no longer pursuing fusion as a goal-oriented energy technology development program. A new strategic plan for the fusion energy sciences program has been developed with new program goals that support plasma science research, emphasize the importance of exploring innovative solutions to technical issues, reinvigorate the search for concepts alternative to the conventional tokamak, and recognize the need to pursue research on the scientific and technological foundations for economically and environmentally attractive fusion energy powerplants through international collaboration.

Taken together, the declining budget and the program restructuring have resulted in an increasing U.S. need to enhance our already considerable participation in international collaborations to achieve our fusion goals most cost-effectively, help maintain technical breadth in the program, and provide access to both existing capital facilities for which we do not have counterparts and future major capital facilities that we could not construct independently.

With energy situations perceived differently than in the United States, the EU and Japan are continuing their goal-oriented fusion energy development programs. The long term goal of these programs is to produce a prototype fusion power plant.

While both the European and the Japanese programs are pursuing the tokamak as the basis for an engineering test reactor, they are pursuing concepts alternative to the tokamak for possible use in demonstration powerplants.

More information about the worldwide fusion programs is contained in the report of the Working Group on International Collaborations on the World Wide Web at the address shown on Page 2.

Overall Strategy

Collaborating with our international partners is one of the tools that allows us to meet our fusion program goals in the most effective way possible. The strategy for employing international collaborations is to:

> ***Identify and make use of opportunities to have U.S. scientists and engineers join with their counterparts in other countries to carry out research that uses the unique capabilities of fusion researchers and fusion facilities worldwide to achieve fusion program goals.***

This statement of our strategy is a revalidation and formalization of the strategic approach to international collaborations that has been so successfully used by the fusion program for the past twenty years.

Proposals for work that supports the strategy are developed by the researchers as an integral part of the ongoing research program. The most successful proposals are those that are supported with roughly equal priority by each participating Party. Because the proposed collaboration is an integral part of the research program, the proposed international activity has the same programmatic priority as the domestic work that it supports and complements.

During the past twenty years, a wide web of productive linkages among fusion programs worldwide has been developed to provide the mechanisms necessary for implementing the collaborations. Most of these linkages involve the U.S. and many of them have been stimulated in some way by the U.S.

The pattern of this web can be drawn as underlying strands of bilateral connections between each of the fusion programs, and as multilateral activities under the auspices of the International Energy Agency (IEA) auspices. Additional strands represent interactions under the auspices of both the International Atomic Energy Agency (IAEA) and various professional technical societies as well as personal relationships among technical personnel.

In the chronological development of this collaborative framework, bilateral activities were crucial to learning about each other, establishing mutual interests, and practicing cooperation. This important role is being played today in the newly evolving bilaterals with China and Korea. As the bilaterals with the European Union, Japan and Russia matured, we found that the common interests extended multilaterally as well and the IEA Implementing Agreements were developed. The latest evolution has been the introduction and growth of the International Thermonuclear Experimental Reactor (ITER) Engineering Design Activities in 1992. Tasks most appropriately carried out by ITER are done in that framework under the auspices of the IAEA; tasks of broad interest but not specific to ITER are carried out under IEA auspices; tasks of specific interest to two parties remain under the bilateral auspices. The intense ITER interaction has so improved communication among most program leaders in the ITER parties that bilateral policy meetings are in some cases now typically held as adjuncts to other international meetings, rather than as stand-alone multi-day investments.

Each of these agreements has its own character, depending upon the individual participants, the facilities being used, the history of interaction, and relationship to the underlying domestic program. Each bilateral program has been an increasingly effective mechanism to advance fusion research with both Parties committed to carrying out the exchange activities.

Strategy-Burning Plasma and Tokamak Performance

ITER

Over the past decade, the U.S. has benefitted immensely from the ITER activities by cost sharing and by focusing the research program to meet the ITER needs. The ITER EDA Agreement among the European Union, Japan, the Russian Federation, and the United States is scheduled to end in July 1998.

The FESAC has recommended that the Department, in concert with its international partners, should build a burning plasma facility at the earliest possible time. ITER currently holds the most promise for fulfilling this recommendation, and both the FESAC and the President's Committee of Advisors on Science and Technology have stated that the U.S. should be prepared to continue its participation in ITER beyond the end of the EDA Agreement, albeit in a manner somewhat restructured from the way it is now proceeding.

The ITER governing body, the ITER Council, has proposed to the ITER Parties a three-year extension of the ITER EDA for work preparing for future decisions on construction and operations of ITER. The Council further recognized needs imposed by budget constraints, and thus has established a Special Working Group (SWG) to propose technical guidelines that should allow the design of minimum-cost options for ITER that will still satisfy ITER's overall programmatic objective. This SWG will also consider broader concepts for the ITER device, and the likely impacts of those concepts on fusion development paths.

In support of the SWG considerations, the U.S. fusion community will work together to develop proposals for lower-cost design options with their associated cost estimates.

In addition, during the three-year extension of the EDA the U.S. will continue collaborative experimental and theoretical fusion sciences research in existing facilities worldwide in support of ITER, test ITER prototype components developed earlier in the EDA to establish operating margins, support the Joint Work Site in San Diego, support a minimum number of scientists and engineers at the three Joint Work sites, and maintain a small U.S. Home Team design effort that will focus on possible lower-cost ITER designs, and advanced modes of ITER physics operation.

In response to another FESAC recommendation on ITER, the U.S. will refocus its technology program away from its previous strong emphasis on ITER and toward meeting the needs of the restructured U.S. fusion program. We anticipate that much of the new technology research will also benefit ITER and will thus be considered dual-purpose.

The U.S. will seek to:

- participate in the three-year extension of the ITER Engineering Design Activities, restructuring that participation to allow development of lower cost design options, exploration of how these options may impact fusion development paths, and a refocusing of the U.S. Fusion technology program on meeting the needs of the restructured U.S. fusion energy sciences program.

Additional Tokamak Activities

The tokamak is presently the most advanced energy containment configuration being pursued by the magnetic fusion energy sciences program. Worldwide there are ongoing tokamak experiments with a wide variety of designs and capabilities. The largest facilities are JET, in Europe, which is now the only fusion device in the world that can operate with a deuterium/tritium (D-T) fuel mixture to produce energy, and JT-60U, in Japan, which has performance capabilities comparable to JET without tritium. With the shutdown of the Tokamak Fusion Test Reactor facility, the U.S. has no fusion experiment that is comparable in size or performance to either JET or JT-60U.

International collaborations that make use of the unique capabilities of JET and JT-60U offer an avenue for achieving important scientific goals of the U.S. fusion program within the limited funding available.

A scientific goal of such JET and JT-60U collaborations would be to complement the ongoing experimental programs at the two U.S. tokamak facilities, DIII-D and C-MOD, in trying to understand how plasma parameters scale to burning plasma conditions. These collaborations will provide valuable scientific information critical to the design and projections of the performance of ITER, which is the principal rationale for these major facilities abroad.

The U.S. will seek to:

- discuss with the proper authorities on the European Union side the possibility that the U.S. could build on our current cooperation to become a major collaborator in the JET experiment. These discussions will make clear that the U.S. would like not only to support scientists and engineers, both at the JET site and possibly at remote sites, but also to fabricate and deliver hardware to the experimental site, as appropriate. The U.S. could potentially contribute hardware in the areas of diagnostics, and auxiliary heating, in the form of additional neutral beams or more efficient antennas for radio frequency heating. Remote operation of JET from the U.S. would also be an objective of this collaboration. Such remote operation would demonstrate a capability for remote operation of ITER.

- implement on JT-60U diagnostic techniques that have played an important role in the development of theoretical models of energy containment. Their implementation on JT-60U would be a critical element in trying to establish the physics basis of confinement in JT-60U experiments.

- continue the active collaboration between DIII-D and JT-60U on the physics of energy confinement and transport barrier formation.

- propose to the international community the establishment of International Topical Collaborations on key scientific and technology issues. These topical collaborations would typically involve multiple experiments worldwide and would act as catalysts in the international fusion community for addressing key scientific issues. Examples of issues that could be addressed are the scaling of energy confinement with machine size, the design of divertors for suppression of impurities and the efficient removal of ash, and the control of plasma dynamics during steady-state operation.

Technical information supporting the recommendations above can be found in the report of the Working Group on International Collaborations on the World Wide Web at the address shown on Page 2.

Strategy-Innovative Concept Development

The development of innovative concepts has again become an important part of the U.S. fusion program strategy. Several of the innovative concepts under investigation within the U.S. are also being pursued by parties that have invested in large facilities aimed at extending plasma performance beyond what can be achieved in U.S. facilities. Collaboration with these programs would allow us to assess the viability, influence the development, and test ideas for further improvement of these concepts.

The U.S. program does not, by itself, have the resources to bring any innovative concept from initial conception to its ultimate embodiment as a fusion powerplant. Hence, U.S. participation in the ultimate development of any innovative concept will depend both on positive results from that concept's development program, and on the formation of international partnerships to complete proof-of-performance and deuterium/tritium burning experiments. Some innovative concepts already have broad international support (e.g., stellarators, spherical tori, and reverse field pinches). For these concepts, an important goal of the collaborations is to maximize the scientific benefit to the programs of the participants, and to begin building the scientific and technical partnerships that will be required for the U.S. program to participate in carrying these concepts toward their powerplant embodiment. For other concepts (e.g., spheromaks, field reversed configurations, and magnetic dipoles) the international effort is small. Positive technical results from U.S. efforts to develop these concepts will be used to interest prospective international partners in joining us in the further development of these concepts.

Innovative confinement concepts in which the U.S. will seek or continue international collaborations include spherical tori, stellarators, and inertial fusion energy. The department will seek to:

- establish a program of international collaborations on spherical tori, including inviting international participation on the National Spherical Torus Experiment in the U.S.

- pursue opportunities for collaboration on stellarators through the Large Helical Device program in Japan and the Wendelstein program in Germany.

- expand bilateral collaborations in Inertial Fusion Energy (IFE), and explore the incorporation of IFE issues into the fusion energy activities at the International Energy Agency.

Technical information supporting the recommendations above can be found in the report of the Working Group on International Collaborations on the World Wide Web at the address shown on Page 2.

Strategy-Advanced Design, Enabling Technology and Materials Development

The advanced design activities look toward the future by considering design options for energy-producing plasma experiments, pathways for fusion development toward electric power plants and other uses for fusion energy, as well as possible embodiments of fusion confinement concepts as power plants.

In the U.S., most enabling technology development is now carried out in support of the ITER Engineering Design Activities (EDA). The principal focus is on superconducting magnet development and R&D related to divertor and first wall issues. Other activities include safety research, plasma fueling and heating, tritium processing systems, remote welding and cutting, and metrology systems.

International collaborations on enabling technologies include: superconducting magnets, plasma facing materials and components, plasma material interactions, wall conditioning and particle control, plasma fueling and fuel process systems and plasma heating systems.

International collaboration in the development of enabling technologies and materials provides opportunities to:

- obtain access to experiments and test facilities worldwide with capabilities not available in the U.S.,
- stay abreast of world wide technology developments, and
- share development costs.

The economic and the safety/environmental features of fusion depend critically on successful outcomes in both enabling technology research and materials development. This will be even more important for advanced high power density machines envisioned with improved plasma physics. The identification and evaluation of high-performance concepts with high-neutron wall load capability, high-power density components, and attractive safety and environmental features is essential for progress on fusion energy. This involves performing research on innovative high performance concepts with large potential payoff.

The development of low activation materials is an important part of this effort. Progress requires advancing the sciences necessary for understanding and evaluating the performance and interactions of an attractive and compatible combination of low activation structural, breeding, cooling and plasma facing materials. Effects of irradiation on materials or components must be conducted in the limited number of fission reactors available in the international community until a high flux 14-MeV neutron source is constructed.

For the longer term, international collaboration on enabling technologies and materials should include: breeding blanket and shield systems; structural materials and radiation effects; remote maintenance and reliability; systems analysis and safety research; and instrumentation.

The Department will seek to:

- begin discussions of future fusion development paths with our international colleagues.

- deploy U.S. technologies on experiments worldwide to access test conditions unavailable domestically, particularly on scientific issues related to long pulse/steady state operation, high power densities, and reliability.

- conduct joint development work on the key feasibility issues for fusion technologies and materials, such as neutron irradiation effects, using unique facilities.

- enlarge the scope of the existing bilateral technology exchanges with Europe, Japan, and Russia.

- continue to participate in the discussions on an international fusion neutron source.

- continue to participate in research on high-performance breeding blankets and joint fission reactor irradiations of advanced materials.

Technical information supporting the recommendations above can be found in the report of the Working Group on International Collaborations on the World Wide Web at the address shown on Page 2.